THE NATURE OF AN ASTRONOMER'S WORK.

BY W. W. CAMPBELL, DIRECTOR OF THE LICK OBSERVATORY, UNIVERSITY OF CALIFORNIA.

FOR nine years it was my duty and pleasure to show the Saturday-night visitors to the Lick Observatory through the great telescope. Their number varied from none on a few of winter's impossible nights up to a maximum of four hundred and thirty. They came from every civilized country, and all trades and professions were represented. They were mainly of those who go about with eyes and minds open. Views through the telescope, descriptions of the instruments and explanations of celestial photographs received their eager attention.

I was greatly interested in observing human nature under these favorable conditions. My experience with the thirty or forty thousand visitors led me to the conclusions, confirmed again and again, first, that, while interest in astronomical subjects is latent and could easily be aroused in a large proportion of the people, yet the simplest facts of the science, open to frequent observation by everybody, are known to comparatively few; and, secondly, that the nature of an astronomer's work is seldom understood.

At a conservative estimate, the majority of the people are unaware that the stars rise in the east, seem to move across the sky, and set in the west, just as the sun and moon do; or that the summer and winter constellations are different. Very few can explain why the form of the moon changes from crescent to full, and from full back to crescent, or can say wherein the planets differ from the stars. There are regiments of young men, fresh from school and college, who, knowing amperes, ohms and volts, can tell you all about the lights in your house, but not one word about the lights in the sky.

The opinion prevails quite generally that an astronomer's duty

consists in sitting all night with his eye at the end of the telescope, "sweeping the heavens," in order to discover new bodies—comets, planets, moons and new stars; and that this is the end and aim of the science. This view is far from the truth. While we in no way discourage the search for new and unknown objects, and, in fact, hail their discovery with delight, we may say that relatively few professional astronomers are thus occupied. The great observatories, with their expensive equipments, cannot afford to engage extensively in such uncertain labor. They leave this work to the small observatories and to the private astronomers, or else they make it a very subsidiary matter. Thus the Lick Observatory, in discovering twenty-seven comets, has devoted certainly less than the one-hundredth part of its resources to that pursuit. The majority of the unexpected comets are, in fact, found by private astronomers, whose four-inch or five-inch telescopes are abundantly powerful for the purpose. The expected returns of periodic comets, on the contrary, are generally detected by professional astronomers. Their mathematical computations tell them when and where to look.

New stars (stars which suddenly appear at points in the sky where none were visible before) and variable stars (those whose brightness varies) are, in the majority of cases, discovered at Harvard College Observatory, for the most part not by direct search, but as the indirect results, or by-products, of an extensive study of the spectra of the stars for another purpose. A few are detected at private and small observatories. Only occasional ones are found at other large observatories, and these are usually detected by chance or by very indirect methods.

It matters little if new stars—comets, satellites, nebulæ or variable stars—are simply "discovered." That is only the beginning of our interest. There are a hundred million bright stars to be seen in the thirty-six-inch telescope whenever we care to look for them. Of what value is it merely to know that one more star has appeared?

Up to the year 1898 some ten thousand nebulæ had been discovered at the various observatories, and their positions and descriptions are published in a catalogue of nebulæ.* The photographs

* The nebulæ are faint, cloudlike forms, some of which are masses of glowing gases, from which stars, planets and their moons will eventually be evolved.

of widely distributed regions of the sky, taken in part by the late Director Keeler, with the Crossley Reflector of the Lick Observatory, and continued by Professor Perrine, indicate that the number not yet discovered, but easily discoverable with this instrument, is in excess of 400,000. These can be found whenever we care to undertake the work. The new ones already discovered, by means of plates taken in the past eight years for other purposes, number nearly a thousand.

The value of the discovery of such objects is not in the discoveries themselves; it is in the opportunity thereby presented for the *thorough study* of those objects. If they are simply discovered and not investigated, the science of astronomy is advanced comparatively little. It is as if Euclid had learned that there is a science of the circle and the sphere, but had not investigated its laws. It is as if the chemist had discovered that there is an element called oxygen, but had not proceeded to determine its properties; or as if Copernicus had been content, like his neighbors, with noting the existence of the principal heavenly bodies, and had not investigated their motions. There certainly have been no more marked cases of successful comet-seeking than those of Barnard and Perrine during the few years when they gave a small fraction of their time, on Mount Hamilton, to this pursuit; but the highest astronomical prizes of the Paris Academy of Sciences were bestowed upon them not so much for their discoveries, as for the opportunities thereby afforded for the further efficient study of cometary bodies, in which the discoverers themselves played leading parts.

I fear that the foregoing references to newly discovered bodies have conveyed the impression that our attention is largely devoted to them. This view is erroneous, and I hasten to correct it. We do not overlook the old and well-known bodies, about which we still have much to learn. These familiar objects, illustrating the general principles of the science, and representing world-life in essentially all its stages of development, deserve and receive the major part of our efforts. Generally less than ten per cent. of astronomical effort is devoted to the search for and study of new objects. It is not practicable to explain in full the nature of the astronomer's investigations, but a few illustrations will be given in general outline.

For three centuries following Copernicus astronomical study was devoted almost exclusively to the solar system,—to the sun, planets and satellites composing this system: their forms and dimensions; their orbital motions and motions of rotation; and the relations of the different members of the system to one another. This work has been brought to a high degree of perfection, in part by astronomers yet living. It would be misleading to say that these problems are completely solved. For example, minute discrepancies in the motions of our moon, of Mercury and of other members of the system remain unexplained, and from time to time added refinements may be expected for all parts of the system. However, it is now possible to predict, with remarkable accuracy, the positions to be occupied by our rapidly moving planets and their satellites for centuries in the future.

In 1898, Witt, of Berlin, discovered an asteroid,—one of the group of small planets in our solar system whose orbits lie between those of Mars and Jupiter. He named it "Eros." It was the 433rd asteroid to be discovered, and the announcement created no comment. However, it was soon found that its orbit was smaller than those of the other asteroids, and that Eros would come much closer to the earth than any other planet. At the times when the earth and Eros are most favorably situated, the distance between them is only 13,500,000 miles. This is about one-third the minimum distance of any other known asteroid. This unexpected fact, of little importance in itself, was epoch-making as a means to an end. It happens that the degree of accuracy with which we can at present measure the distance of the earth from the sun, some 93,000,000 miles (the principal astronomical unit of distance), depends upon the closeness of an asteroid's approach to us. By observations of Eros, we should, therefore, obtain a threefold more accurate knowledge of the distance of the earth from the sun than we now possess. When the asteriod was comparatively close to the earth, in 1900-1, some thirty observatories throughout the world co-operated in securing a very accurate and extensive series of observations for this purpose. The measurement of the hundreds of photographic plates of Eros and the stars in that part of the sky, the computations connected therewith, and the determination of the resulting value of the sun's distance from us, will require the labor of at least thirty skilled men during five years or more. This case illus-

trates unusually well the fact that the discovery of an unknown body is valuable substantially in proportion to the opportunity thereby afforded for making useful extensions to our knowledge. Simply to know that there is a planet Eros, travelling in a certain orbit, has little more value than as a satisfaction to human curiosity. But to take scientific advantage of the discovery of Eros is to improve our knowledge of all celestial distances; or, in other words, to determine with greater accuracy the scale on which the universe is constructed.

Within the past half-century improvements in instruments and methods have enabled us to pass from the problems of our own little system to those of the incomparably more remote and extensive stellar system, and the present tendency of astronomy is strongly in the latter direction.

I wish it were possible to give here an idea of the valuable and extensive investigations which have been made with meridian instruments — instruments which measure the positions of the stars on the celestial sphere as they cross the meridian. At least one-half the energies of astronomers in the past one hundred and fifty years have been devoted to making and reducing meridian observations. These have given us our star catalogues, containing the extremely accurate positions of one hundred thousand stars, and the approximate positions of a million more. The data contained in these catalogues are the foundation upon which the entire superstructure of mathematical astronomy is built. These collections of star-positions, acquired at the cost of great skill, patience and toil, are perhaps the richest of astronomy's possessions. And their values increase constantly with time; for, as the stars are slowly changing their apparent positions on the celestial sphere, and as their rates and directions of motion are determined by comparing their present-day positions with their former ones, it follows that the earlier accurate observations have values directly proportional to their age.

Unfortunately these catalogue positions tell us only the direction in which a star lies and nothing at all as to its distance. The component of motion at right angles to the line of sight is expressed in angular measure, and cannot be converted into linear motion,—miles per second, for example,—until the star's distance becomes known. We have approximate knowledge of the distances of only a few dozen stars. Our present means are ap-

parently inadequate to measure the distances, even roughly, of more than a few hundred stars; but half a dozen astronomers are struggling with the problem, and it is hoped that appreciable improvement in methods will result. At no other point in the science is accurate knowledge more keenly needed.

The two foregoing paragraphs refer only to that component of a star's motion which is at right angles to the line joining the star and observer. Now, every star has at the same time a component of motion toward or away from the observer, of which the meridian instrument has taken and can take no account. Fortunately the spectroscope is able to measure this component, and eight leading observatories have each a department engaged in observing the brighter stars with a great telescope and spectrograph (an instrument for photographing spectra), in order to determine their motions of approach and recession.

Given the component of motion at right angles to the line of sight as determined by meridian and parallax observers, and the component parallel to the line of sight supplied by the spectrograph, we could readily ascertain the actual motion of the star *with reference to the observer.* However, this would be in itself of little value in a study of the stellar system as a whole, unless we have means of eliminating the effects of the observer's motion, since the observed motion is not the star's motion with reference to the stellar system, but it is a compound of its motion and that of the observer.

Astronomers have known for a century that our solar system as a whole is travelling toward the constellation Lyra or Hercules and away from the opposite part of the sky, but an uncertainty of at least ten degrees exists as to the exact direction. Until recently little has been known as to the speed of our motion, the estimates of different astronomers varying from five to thirty miles per second. In order to obtain a satisfactory solution of this problem, if possible, the great Lick Telescope, with the Mills Spectrograph attached to it, has been used three nights per week for the past ten years to secure the photographic observations needed, and the work will be continued several years more. The labor required to measure and reduce the photographs is three or four fold that involved in securing the plates. Observations of the stars visible only in the Southern Hemisphere are also required before the solution can be made satisfactory, and

a branch observatory, located on a mountain-top in the north-eastern suburbs of Santiago, Chile, is getting these observations, thanks to the generosity of Mr. D. O. Mills.

If we would learn the nature of the stars, whether they are solid, liquid or gaseous, whether they are new or comparatively old, whether their temperatures are high or relatively low, we should begin by making a study of our own star—our sun. It is the only star near enough to present a disk, and therefore to let us study it in some detail. All other stars remain as points of light even when the powerful telescopes magnify them three-thousandfold. There are observatories established for the sole purpose of investigating the sun, and many astronomers are constantly employed in studying the structure of all its visible portions, the laws followed by the heat and light radiated from all parts of its surface, and the conditions indicated by the spectrum of each part. It is not too much to say that our physical knowledge of the stars would to-day be almost a blank if we had been unable to approach them through the study of our sun. Several of the most interesting portions of our sun are invisible, except at times of solar eclipse. Our knowledge of the sun will be incomplete until these portions are thoroughly understood; and this is the reason why eclipse expeditions are despatched, at great expense of time and money, to occupy stations within the narrow shadow belts in whatever corners of the earth these events occur.

A score of other departments of our science call for systematic work, according to programmes equally extensive. For example, there are the nebulæ,—their forms, their temperatures, their spectra, their motions, their relations to the stars already existing, and the principles in accordance with which they themselves will in long ages condense and form other stars.

Double stars constitute a large department. The recent work of Professors Aitken and Hussey, of the Lick Observatory, has shown that, on the average, one star in eighteen is attended by a bright companion sun, visible through powerful telescopes, but not at all to the unassisted eye. Observations with the Mills Spectrograph of the Lick Observatory, the Bruce Spectrograph of the Yerkes Observatory, and other similar instruments, have established that at least one star in six is attended by massive close companions, invisible in the most powerful telescopes. All these systems, both visible and invisible, call for investigation.

There are the variable stars, those thus far discovered numbering more than two thousand. Why are they brighter at one time than at another? The causes in nineteen cases out of twenty are unknown, and the determination of these causes constitutes a great problem. Half a dozen small observatories, extending around the world near the parallel of thirty-nine degrees north latitude, are engaged exclusively in studying the variation of terrestrial latitudes; for it has been shown that the position of the earth's equator and, therefore, our distance from the equator (our latitude) changes back and forth through a range of sixty feet. A few large observatories are devoting decades to the accurate measurement of the brightness of the stars.

The resources of a dozen observatories are devoted to the photographic charting of the heavens, each photograph requiring accurate measurement and computation—an enormous piece of work, demanding twenty years or more for its completion. A better realization of the magnitude of the labor involved will be gained, perhaps, by calculating that a dozen observatories for twenty years, *on one problem,* is equivalent to one observatory's time and effort for two hundred and forty years!

There are the comets, which excite great public and scientific interest, not only because they are extremely interesting objects, but because they come close to us, and since they come and go, they must be studied while here. How and where did they originate? What is their composition? What conditions prevail in them? In other words, what is a comet, and what is its relation to other celestial objects?

Not to illustrate further, it should be said that these lines of work, as well as the far greater number of unmentioned ones, all bear upon the solution of the two great problems which at present compose the science of astronomy. These problems, perhaps the most profound in the realm of matter, may be stated thus:

First, a determination of the structure of the sidereal universe; of the form of that portion of limitless space occupied by our stellar system; of the general arrangement of the sidereal units in space, and their geometrical relations to one another; and of their motions in accordance with the laws of gravitation;

Second, a determination of what the nebulæ, stars, planets, satellites, comets and other members of the universe really are:

what are their chemical constitutions; their physical conditions and relations to one another; what has been the history of their development, in accordance with the principles of sidereal evolution; and what has the future in store for them, and for the system as a whole.

Observatories supply accurate time signals wherever telegraph and cable extend. These signals are regulated by observations of stars whose positions have been previously determined by meridian instruments. Many modern boundary lines between nations are located by means of observations of stars whose exact positions in the sky are defined in the star catalogues. The ship's captain ascertains his latitude and longitude, and therefore the course of his vessel, by observations of the sun, moon and stars, whose positions are prepared for him in advance by astronomers, as a result of their extensive observations and extremely laborious calculations.

That the main results of the astronomer's work are not so immediately practical does not detract from their value. They are, I venture to think, the more to be prized on that account. Astronomy has profoundly influenced the thought of the race. In fact, it has been the keystone in the arch of the sciences under which we have marched out from the darkness of the fifteenth and preceding centuries to the comparative light of to-day.

Who can estimate the value to civilization of the Copernican system of the sun and planets? A round earth, an earth not the centre of the universe, an earth obeying law, an earth developed by processes of evolution covering tens of millions of years, is incomparably grander than the earth which ante-Copernican imagination pictured.

It is of priceless value to the human race to know that the sun will supply the needs of the earth, as to light and heat, for millions of years; that the stars are not lanterns hung out at night, but are suns like our own; and that numbers of them probably have planets revolving around them, perhaps in many cases with inhabitants adapted to the conditions existing there. In a sentence, the main purpose of the science is to learn the truth about the stellar universe; to increase human knowledge concerning our surroundings, and to widen the limits of intellectual life.

W. W. CAMPBELL.